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6-, 10-, and 12-month-olds remember complex dynamic events across 2 weeks

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ABSTRACT

Whereas infants' ability to remember simple static material (e.g., pictures) has been documented extensively, we know surprisingly little about infants' memory of dynamic events (i.e., events unfolding in time) in the first year after birth. Although there is evidence to suggest that infants show some kind of sensitivity toward *complex* dynamic events (i.e., events involving agents and a storyline) as indicated by visual engagement in the first year after birth, 16- to 18-month-olds are hitherto the youngest infants documented to *remember* such material. Using a visual paired-comparison (VPC) task, in Experiment 1 we examined 6-, 10-, and 12-month-olds' ($N = 108$) ability to encode and remember cartoons involving complex dynamic events across 2 weeks. Results showed that all age groups remembered these cartoons. To investigate further the role of a complex storyline, in Experiment 2 we assessed the memory of 107 infants of the same age groups for similar cartoons but without coherent storyline information by scrambling the temporal presentation of the information in the cartoons. The results showed that the two youngest age groups did not remember this version. To our knowledge, this is the first experiment to document memory for such complex material in young infants using VPC.

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Introduction

Infant cognition is difficult to capture. Infants cannot simply tell us what they think or how much they remember. Therefore, scientists must rely on methods suitable for testing infant cognition. These methods must allow infants to *show* us instead of *telling* us what they think. The development of suitable methods for assessing infant memory in the 1980s was to a large degree responsible for the way we consider memory in infancy today. Because of these methods, we now have a much better understanding of infants' ability to remember, such as for how long they remember, and the importance of cues (e.g., Bauer, 2007; Hayne, 2004).

A key method responsible for these findings is the visual paired-comparison (VPC) paradigm, which is widely acknowledged for assessing recognition memory in infancy (e.g., Hayne, 2004; Krøjgaard et al., 2020). A great strength of this paradigm is that—while predominantly employed for infants—the methodology has also been successfully used for other age groups, ranging from about 3 months and all the way up to adulthood (e.g., Krøjgaard et al., 2020; Richmond et al., 2007). Whereas other measures indicative of memory often require a certain degree of motor actions or verbal skills, this tool is ideal for infants given the exclusive reliance on looking behavior toward a given stimulus.

The stimuli used in VPC tasks have typically, in part for methodological reasons, been of low complexity, including simple abstract patterns (e.g., Fagan, 1974; Fantz, 1964) and still pictures such as photographs of a face (e.g., Bushnell, 2001; Fagan, 1974; Hayne et al., 2016; Taylor & Herbert, 2014). In their daily lives, however, infants are more likely to experience acting people than static faces and are more exposed to spoons and chairs involved in concrete use than to static pictures of such objects. Hence, it is difficult to provide clear conclusions from these low-complexity studies as to how well infants remember dynamic events depicting more complex narratives across a delay (i.e., longer than a few seconds). By *dynamic events,* we refer to events involving agents conducting intentional actions unfolding in time. Some researchers (e.g., Gross et al., 2002) have argued that the use of simple static stimuli may have been the reason why infants have succeeded only with relatively short retention intervals on VPC tasks compared with performance on other memory tasks such as the imitation paradigm and the mobile conjugate reinforcement paradigm.

In a typical VPC task, the infants are randomized to watch either Stimulus A or Stimulus B (of equivalent complexity) during encoding for a predetermined amount of time or until the infants show signs of familiarization. Importantly, no a priori preference for the stimuli must be present. After a delay, the infants' memory is tested by simultaneously presenting the infants with the now familiar stimulus next to the novel stimulus. At test, and because the design is counterbalanced, any *systematic* preference (i.e., increased looking time) at the group level for either the familiar or novel stimulus can be attributed to memory (e.g., Bahrick & Pickens, 1995).

When attempting to understand when infants begin to remember dynamic events, at least two questions seem important. First, when do infants begin to *comprehend* dynamic events? Second, when do infants begin to *remember* such dynamic events?

Very few studies have examined when infants begin to comprehend dynamic events or, more directly, whether they react to the comprehensibility of the material. Based on earlier studies by Anderson and colleagues (1981) suggesting that children's looking time in relation to television is based on comprehension processes, Pempek et al. (2010) set out to investigate this in infancy. Pempek et al. (2010) exposed 6-, 12, 18-, and 24-month-olds to normal and distorted movie clips from the TV program *Teletubbies,* Whereas the normal versions were intact, the distorted versions involved either reversing the speech track or re-arranging the order of 5-s excerpts of the movies. The results revealed that the 18- and 24-month-olds, but not the 6- and 12-month-olds, preferred (i.e., looked longer toward) the normal versions, suggesting that only from 18 months of age and beyond did infants react to comprehensibility of the movie sequences as indicated by measures of attentional engagement (see also Richards & Cronise, 2000).

However, some evidence suggests that detection of disruptions of displayed dynamic events may begin even earlier. Baldwin et al. (2001) presented 10- and 11-month-olds with brief movie clips involving simple action sequences (e.g., picking up a towel and placing it on a rack). After familiarization, the infants at test showed renewed interest in versions where the action sequences were paused while the actor attempted to finalize the action, whereas infants did not show an increase in looking to versions where the pauses were inserted after action completion. These results suggest that infants parsed the action sequences as coherent intentional events, indicating early detections of intentional actions. Thus, infants may possess such understanding possibly already late in the very first year or around 18 months of age (see also Anderson & Hanson, 2010; Woodward et al., 2001).

When it comes to remembering dynamic material early in infancy, Morgan and Hayne (2011) investigated recognition memory by means of looking time across different delays for 1-, 2-, 3-, and 4-year-olds by use of cartoon faces that either blinked their eyes or moved their mouth. Whereas the 1-year-olds displayed recognition memory only at the immediate test, the 2-year-olds did so for up to 24 h, the 3-year-olds did so for up to 1 week, and the 4-year-olds showed signs of remembering for up to 6 months. Focusing on performance around the first year after birth, thus, infants seem unable to remember the material across longer retention intervals. As stated by Hayne et al. (2016), infants' mnemonic performance on the VPC is typically considered quite poor relative to evidence obtained using other memory tasks (for a review, see Hartshorn et al., 1998). However, one question concerns whether this difference in performance may be caused by the chosen stimulus material.

Another study employing dynamic material is the study by Bahrick et al. (2002, Experiment 1) investigating whether 5.5-month-olds could remember movies depicting women doing simple repetitive actions such as brushing their hair recorded in a featureless setting. Using a VPC task, the authors showed that the infants showed evidence of remembering the actions (although not the faces) as measured by looking time of the women after a 7-week delay, suggesting that actions in particular may be stored in infants' memory. Note, however, that although both Morgan and Hayne (2011) and Bahrick et al. (2002) used dynamic events (i.e., not static pictures) as stimulus material, the events were only dynamic in the sense that they involved agents and unfolded in time (e.g., a character blinking) but not dynamic in the sense that they involved a narrative with a beginning and an end (e.g., picking up a towel and putting it in place; cf. Baldwin et al., 2001). For the sake of convenience, in the following we distinguish between these two types of dynamic events and refer to events involving repetitive actions but without a narrative (e.g., brushing your hair) as *simple dynamic events,* whereas we refer to more complex events with agents performing intentional acts that *do* contain a narrative structure involving a beginning and an end as *complex dynamic events.*

Infants' ability to remember *complex* dynamic events has recently been examined in our lab (Kingo & Krøjgaard, 2015; Kingo et al., 2022; Sonne et al., 2016, 2017, 2018). In these studies, variations of two cartoons (about a "snowman" or a "crab") were employed, each depicting an agent performing intentional acts and involving a straightforward narrative with a beginning and an end. The snowman cartoon depicted a snowman in a winter landscape attempting—and in the end succeeding—to make a hat land on his head. The crab cartoon displayed a crab at a beach throwing a ball up in the air and grabbing it—and unfortunately ending with puncturing the ball with his claws. Using the VPC paradigm, the results from these experiments have repeatedly shown that infants around 16 to 20 months of age show signs of remembering the complex dynamic events depicted in these cartoons across a 2-week period as evidenced by a familiarity preference (e.g., Sonne et al., 2016, 2018). Even though the material consisted of cartoons (chosen because they allowed us to have complete control over the stimulus material), the cartoons—by portraying a brief narrative including agents performing actions with objects—involved dynamic aspects similar to those encountered in the real world.

In summary, existing evidence suggests that infants show signs of sensitivity toward dynamic events at least around 18 months of age and maybe even earlier. With regard to *remembering* dynamic material, there is evidence to suggest that even 6-month-olds may remember *simple* dynamic events across substantial delays (i.e., 7 weeks; cf. Bahrick et al., 2002). However, memory of *complex* dynamic events has hitherto not been examined in infants younger than 16 to 18 months (e.g., Sonne et al., 2016). Because recent evidence suggests that narrative information in such complex dynamic events may be crucial for subsequent recognition (Sonne et al., 2018), we set out to examine 6-, 10-, and 12-month-olds' memory of complex dynamic events across a 2-week retention interval. This was done by means of the snowman and crab cartoons depicting complex dynamic narratives that have proven to be adequate for older infants. Investigating young infants' performance on the VPC task using complex material could potentially provide important insights regarding the development of memory for dynamic events with a complexity more similar to the everyday events typically experienced by infants.

The present study

Using the VPC paradigm, here we report two experiments in which we examined 6-, 10-, and 12-month-old infants' ability to remember cartoons across 2 weeks focusing on their looking time as measured by eye-tracking. The age groups were chosen to test infants considerably younger than in previous studies while covering a broad age range in the second half of the first year after birth. Although the results from Bahrick and colleagues suggest that very young infants remember actions across long delays (e.g., Bahrick et al., 2002; Bahrick & Pickens, 1995), to our knowledge no one has examined whether infants in the first year after birth show signs of remembering complex narrative sequences (i.e., events involving agents as well as a beginning and an end). This was what we set out to investigate in Experiment 1. The 2-week retention interval was chosen to be able to compare the results with previous studies using the same stimulus material and retention interval (e.g., Sonne et al., 2018).

Because this was the first study to assess memory of complex dynamic material within the first year after birth across 2 weeks, the hypotheses were tentative at best. If the infants showed signs of remembering the cartoons as indicated by a systematic preference in looking time as previous studies have found with older infants tested with the same stimulus material (e.g., 18-month-olds; Kingo & Krøjgaard, 2015; Sonne et al., 2018), we expected to see a familiarity preference in Experiment 1. However, due to the fact that this was the first study testing memory for complex material in such young infants, we could not know whether they would be able to remember the material at all (i.e., as evidenced by conventional testing against chance level; see Results section). Furthermore, based on previous findings (e.g., Kingo et al., 2022), potential age differences could be expected. If the infants did remember the cartoons, we expected stronger (familiarity) preferences with older infants.

Based on previous findings with similar material, we expected the storyline or the narrative content to support the infants' memory of the material (Kingo & Krøjgaard, 2015; Sonne et al., 2018). We added Experiment 2 to examine whether this was the case.

Experiment 1

Method

Participants

A total of 108 infants participated in Experiment 1. Of these infants, 36 were 6-month-olds (M = 6.13 months, SD = 0.12; 21 girls and 15 boys), 36 were 10-month-olds (M = 10.02 months, SD = 0.19; 19 girls and 17 boys), and 36 were 12-month-olds (M = 12.07 months, SD = 0.26; 21 girls and 15 boys). The number of infants was chosen to be comparable to previous studies using the same material (e.g., Sonne et al., 2018). The infants were primarily recruited via birth registries, and a few were recruited by word of mouth. The infants were healthy, full-term, and primarily living in families with middle or high socioeconomic status based on educational level. A total of 13 infants were tested but later excluded due to: fussiness (n = 3) or too brief looking time during encoding (n = 8) or test (n = 2). We first excluded infants looking for a shorter duration than 1 s in both sessions. Furthermore, we excluded all infants who looked for a shorter duration than 3 standard deviations below the overall group mean; however because this number was below zero for the encoding session and thus not meaningful as an exclusion criterion, we decided to employ an exclusion criterion of 2 standard deviations here to remove infants who almost did not watch the cartoons.

Materials

Two custom-made 30-s cartoons previously used in several studies from our lab (e.g., Kingo & Krøjgaard, 2015; Sonne et al., 2016, 2017, 2018) were employed (see Fig. 1). One cartoon depicted a snowman in a winter landscape. The storyline involved a snowman entering the scene from the left and approached a hat lying on the ground, and then he started jumping up and down, finally making

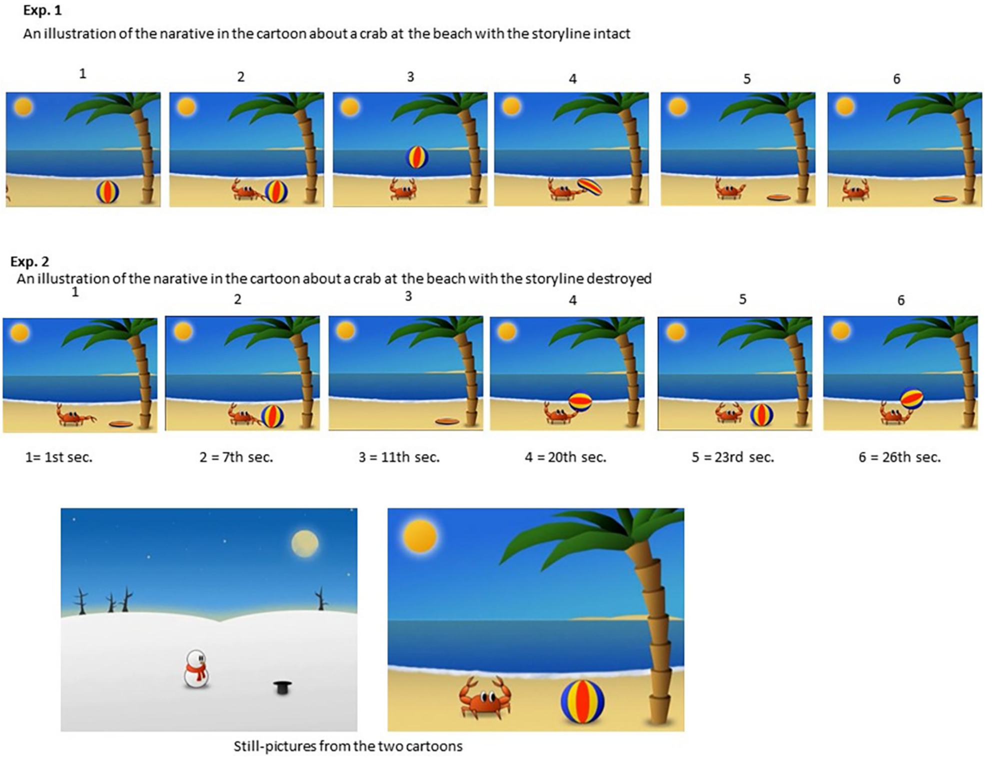

Fig. 1. Outline of the narrative in the crab cartoon as depicted in both Experiments 1 and 2 and still pictures from the two cartoons used. Exp., Experiment; sec., second.

the hat land on the snowman's head. The snowman smiled and exited from the right. In the crab cartoon, a crab entered the scene from the left and noticed a ball lying on a beach, and then the crab started playing with the ball, making it bounce a couple of times before being punctured by one of the crab's claws. The crab exited the scene to the right. Both cartoons were without sound to avoid interference when at the second visit (i.e., the test), presenting both cartoons simultaneously.

Design and procedure

The infants visited the lab twice. At the first test session, the infants were introduced and familiarized to one of the two cartoons (half of the infants were presented with the crab cartoon, whereas the other half saw the snowman cartoon). As in the previous studies using similar material, the infants watched the same cartoon four times in a row to ensure encoding while they were being eye-tracked. Following a 2-week delay (M = 14.09 days, SD = 1.08, range = 11–17), they were presented with the now familiar cartoon right next to the novel cartoon, again while they were being eye-tracked. Both cartoons were presented twice in succession with left/right orientation counterbalanced.

Eye-tracking setup and data extraction

At both sessions, we eye-tracked the infants' visual preferences by use of a Tobii X120 (Tobii Technology, Stockholm, Sweden), recording fixations at 120 Hz with 0.5° accuracy on a 30-inch LCD monitor. The total visual angle of the screen was 40° (width) × 25° (height), and the visual angle of the stimuli area was 33° (width) × 16.5° (height). The infants' eyes were approximately 70 cm from the eye-tracker. A Tobii Fixation Filter (default) was used. Furthermore, we used the semi-automated five-point calibration procedure offered by Tobii Studio. The experimenter judged whether the calibration was satisfactory based on visual inspection of the calibration output provided by Tobii Studio. Calibration was continued until the calibration results were deemed satisfactory. The cartoons were presented using E-Prime software (Psychology Software Tools, Pittsburgh, PA, USA). To assess looking time during the first session, we created a simple area of interest (AOI) covering the whole visual field, and for the second session we created two AOIs, each covering a cartoon. Within each of these AOIs, the infants' fixation duration was assessed, providing us with a measure of the infants' absolute looking time within these predefined AOIs. For the first session, we looked at the full presentation of the stimuli as well as at each iteration on its own (four iterations). For the second session, two iterations were recorded originally to enable additional analyses of changes from the first iteration to the second iteration. However, because these analyses were dropped and following previous studies highlighting that the first iteration could be considered the "cleanest" VPC measure (see Kingo et al., 2022), only data from the first of these iterations were considered.

Results and discussion

Analytical approach

The strategy of analyses was as follows. First, we analyzed whether the infants encoded the presented material. Preliminary analysis by use of an analysis of variance (ANOVA) was run to check for differences in relation to the presented cartoon or age differences. This was followed by a mixed-model repeated-measures ANOVA to investigate whether the infants got familiarized to the cartoons throughout the four iterations. To examine whether the infants remembered the cartoons, we provided a preliminary analysis of looking time during test to investigate whether differences were to be found in relation to the presented material or in relation to the age group. This was followed by analyses focusing on *t* tests by comparing the infants' proportional looking to the novel cartoon with chance level (.50). This strategy was chosen because proportional looking is the standard measure used in the VPC paradigm, and we ran *t* tests following convention (e.g., Hayne et al., 2016; Richmond et al., 2007). Finally, a planned ANOVA was run to investigate possible age differences. For all nonpreliminary analyses, we present the results from both traditional and Bayesian statistics to ensure both dichotomous and more continuous interpretation of the hypothesis testing.

Looking time during encoding

An important prerequisite when assessing the infants' memory of the cartoons was that the infants watched and were familiarized to the cartoons. Therefore, we first present the results from the encoding session. As a preliminary analysis, we first investigated whether we would find any differences in relation to total looking time during encoding with regard to age group and cartoon. An ANOVA with cartoon (crab vs. snowman) and age group (6 vs. 10 vs. 12 months) as between-participants factors and with total looking time across the four iterations during encoding as the dependent variable revealed no main effects and no interactions (all *p*s > .512). Thus, in the following, the encoding data were collapsed across cartoons and age groups.

A repeated-measures ANOVA with looking time at encoding (looking time of Iteration 1 vs. Iteration 2 vs. Iteration 3 vs. Iteration 4) revealed an effect of encoding, $F(3,321) = 23.77$, $p < .001$, $\eta_p^2 = .182$, $BF_{10} = 1.047e^{11} \pm 0.54\%$ (see Fig. 2). Inspecting Fig. 2, we see a systematic and reliable decline in looking time across iterations. Thus, the infants encoded and were familiarized to the cartoon presented at the first visit. Thus, results cannot be explained by differences in encoding.

Did the infants remember the cartoons?

Again, as a preliminary analysis, we investigated whether we would find any differences in total looking time during test with regard to age group and cartoon. An ANOVA with cartoon (crab vs. snowman) and age group (6 vs. 10 vs. 12 months) as between-participants factors and with looking time during test as the dependent variable revealed no main effects and no interactions (all *ps* > .082). Therefore, the following analyses were collapsed across cartoons. However, we maintained age group as a factor moving forward because we had a priori hypotheses for age differences in the proportional looking.

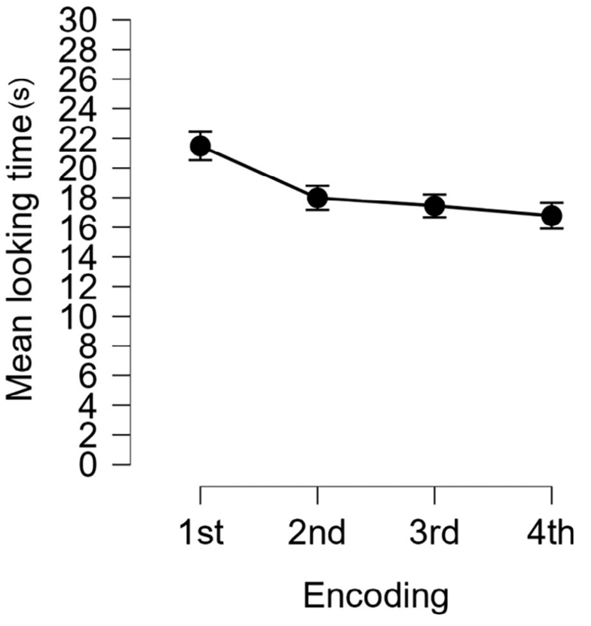

Fig. 2. Looking time during encoding for each of the four iterations of the cartoons for Experiment 1. Error bars show 95% confidence intervals.

To test the infants' memory of the cartoons, we used the conventional method for testing this when using the VPC paradigm (e.g., Richmond et al., 2007; Roder et al., 2000). Thus, we calculated the proportional looking to the novel cartoon by dividing the looking time to the novel cartoon by the looking time to both cartoons. This resulted in a number between 0 and 1. Following convention, we ran the standard tests for testing retention, namely by use of planned *t* tests compared with chance level (.50) (e.g., Hayne et al., 2016; Morgan & Hayne, 2011).

When looking at the age groups separately, we see that all age groups clearly remembered the cartoon they had been presented with at the first session. We compared the proportional looking to the

Table 1
Descriptives and results from one-sample *t* tests against chance level (.50) for the three different age groups for both experiments.

Experiment 1	Traditional statistics						Bayesian statistics	
	Descriptives		*t* test				*t* test	
	M	*SD*	*t*	*df*	*p*	*d*	BF_{10}	Error
Age group								
12-month-olds	.33	.19	−5.34	35	<.001	−.89	3420.795	±1.519e^{-9}%
10-month-olds	.42	.17	−3.00	35	.005	−.50	7.861	±1.967e^{-7}%
6-month-olds	.44	.18	−2.06	35	.044	−.34	1.165	±0.022%
Experiment 2	Traditional statistics						Bayesian statistics	
	Descriptives		*t* test				*t* test	
	M	*SD*	*t*	*df*	*p*	*d*	BF_{10}	Error
Age group								
12-month-olds	.38	.22	−3.26	35	.002	−.54	14.219	±6.414e^{-8}%
10-month-olds	.47	.22	−0.71	35	.483	−.12	0.042	±0.042%
6-month-olds	.49	.20	−0.44	34	.662	−.07	0.199	±0.042%

Note. BF_{10}, Bayes factor for the alternative hypothesis with an uninformative prior. Numbers refer to proportional looking to the novel cartoon.

novel cartoon with chance level (.50) by running planned *t* tests. See Table 1 for descriptives and results. This was—in all cases—evidenced by reliable familiarity preferences (see Fig. 3).

To test for possible age differences, we ran an ANOVA with age group (6 vs. 10 vs. 12 months) as a between-participants factor. We found a main effect of age group, $F(2,105) = 3.46$, $p = .035$, $\eta_p^2 = .062$, $BF_{10} = 1.41 \pm 0.01\%$ (although with a low Bayes factor). Bonferroni post hoc tests revealed that this difference was due to a difference between the 6-month-olds and the 12-month-olds ($p = .041$, $BF_{10,U} = 3.05 \pm 0.008\%$). Referring to Table 1, we see that the oldest age group had a lower mean compared with the youngest age group, thereby reflecting a stronger familiarity preference.

The results from Experiment 1 showed that the infants aged 6 to 12 months remembered the complex dynamic material across 2 weeks but also that the strength of the evidenced familiarity preference seemed to increase with age. These patterns were confirmed with both traditional and Bayesian analyses. As previously stated, whereas young infants have been shown to remember *simple* dynamic events (e.g., a repetitive action like blinking), *complex* dynamic events with agents involving a storyline have hitherto not been documented to be *remembered* by infants under 1 year of age. The results from the current study challenge this potential "barrier." Not only did the infants, including the 6-months-olds, show signs of remembering such complex material as evidenced by looking behavior, we find it likely that the narrative structure was facilitating for the remembering of these complex dynamic events. Recent evidence testing 18-month-olds' memory suggests that the complex narrative information inherent in these cartoons may even be important for remembering these events (Sonne et al., 2018). Sonne and colleagues (2018) contrasted intact versions of the cartoons with (a) pixelized versions (with the resolution severely hampered while color, movement, and duration were preserved) and (b) scrambled versions (with static conceptual information preserved while the storyline was disrupted). The results revealed that the 18-month-old infants remembered only the intact versions across the 2 weeks, suggesting that it was the complex narrative information (and not, e.g., static conceptual information) that made the memory trace survive. We set out to investigate whether the storyline indeed supported the infants' memory in Experiment 2.

Experiment 2

Given that the infants in Experiment 1 could also be said to remember the material due to basic static conceptual information such as the agents (crab or snowman) or objects (e.g., hat or tree) within the cartoons, we wanted to rule out this explanation by running Experiment 2. Based on previous findings with similar material, we expected the storyline or the narrative content to support the infants'

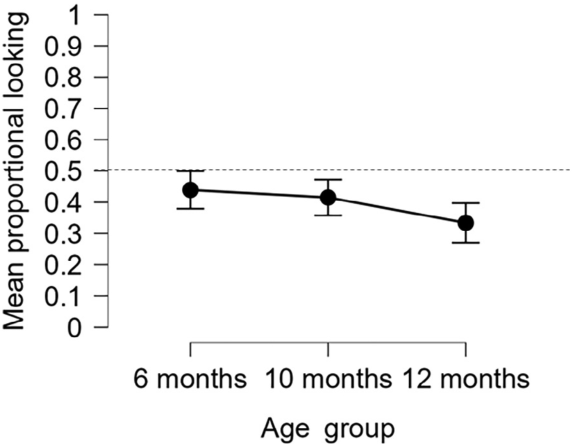

Fig. 3. Proportional looking to the novel cartoon during test for each age group. Error bars show 95% confidence intervals. The dotted line represents chance level.

memory of the material (Kingo & Krøjgaard, 2015; Sonne et al., 2018). Following the study by Sonne et al. (2018) looking at 18-month-olds' memory for cartoons to investigate whether the infants primarily remembered the cartoons due to static conceptual information or whether the storyline indeed was important, we used a scrambled version of the cartoons that was designed to disrupt the coherency of the storyline (the temporal dynamics) while preserving the static conceptual elements (e.g., agents, objects). In the scrambled version, the temporal presentation of the cartoons was broken down into small units of 1-s duration and then presented in a scrambled order (Sonne et al., 2018). Given that we had no existing evidence to draw on with the age groups 6, 10, and 12 months, the hypothesis was tentative. However, based on previous findings, it could be expected that if the narrative content is supporting memory in young infants too, then the infants would not be able to remember these versions of the cartoons.

Method

Participants

A total of 107 infants participated: 35 6-month-olds (*M* = 6.27 months, *SD* = 0.21; 20 girls and 15 boys), 36 10-month-olds (*M* = 10.08 months, *SD* = 0.24; 19 girls and 17 boys), and 36 12-month-olds (*M* = 12.13 months, *SD* = 0.27; 15 girls and 21 boys). The infants were primarily recruited via birth registries, and a few were recruited by word of mouth. The infants were healthy, full-term, and primarily living in families with middle or high socioeconomic status based on educational level. Based on the same exclusion criteria as in Experiment 1, a total of 9 infants were tested but later excluded due to fussiness ($n = 3$), technical error ($n = 2$), or too brief looking time during encoding ($n = 3$) or test ($n = 1$).

Materials

We used the cartoons developed for Sonne et al. (2018) referred to as the scrambled version. Here identical versions of the cartoons used in Experiment 1 were changed by dividing the temporal presentation into small units, each lasting 1 s. The units were then arbitrarily scrambled to a new order (ensuring that no adjacent units were kept in their original order). This was done to disturb the storyline while maintaining information of conceptual value such as agents and objects (see Fig. 1).

Design, procedure, and eye-tracking

Everything was kept identical to Experiment 1 except for the use of the scrambled version of the cartoons. Thus, the infants again returned after 2 weeks (*M* = 13.81 days, *SD* = 0.85, range = 10–16) for the test session.

Results and discussion

Analytical approach

We followed the same plan for analyses as in Experiment 1. Finally, we also compared the two experiments in an ANOVA.

Looking time during encoding

Preliminary analysis using an ANOVA with cartoon (crab vs. snowman) and age group (6 vs. 10 vs. 12 months) as between-participants factors and total looking time across the four iterations during encoding as the dependent variable revealed no main effects and no interactions (all $ps > .377$). Therefore, in the following we collapsed the encoding data across cartoons and age groups.

Again, a repeated-measures ANOVA with looking time at encoding (looking time of Iteration 1 vs. Iteration 2 vs. Iteration 3 vs. Iteration 4) as within-participants factors revealed an effect of encoding, $F(3,312) = 44.95$, $p < .001$, $\eta_p^2 = .302$, $BF_{10} = 1.140e^{21} \pm 0.83\%$ (see Fig. 4). As displayed in Fig. 4, the means of looking time were systematically declining as a function of encoding.

Did the infants remember the cartoons?

An ANOVA with cartoon (crab vs. snowman), and age group (6 vs. 10 vs. 12 months) as between-participants factors and with looking time during test as the dependent variable revealed no main

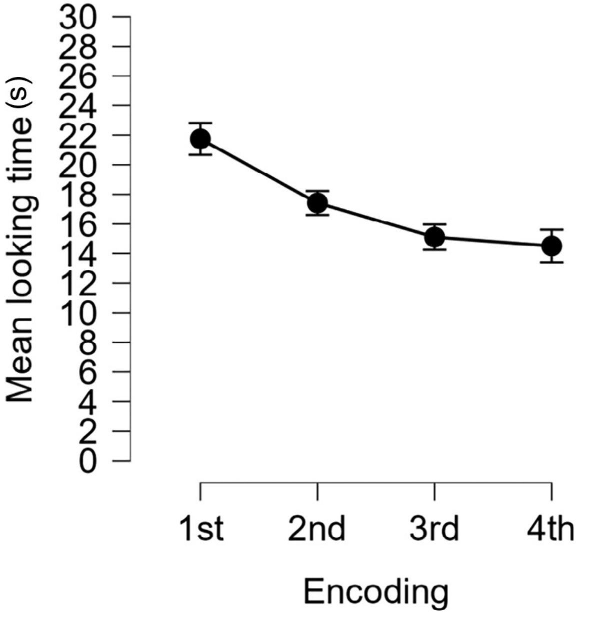

Fig. 4. Looking time during encoding for each of the four iterations of the cartoons for Experiment 2. Error bars show 95% confidence intervals.

effects and no interactions (all *ps* > .123). Again, we collapsed the following analyses regarding cartoons while maintaining age group as a factor moving forward because we had a priori hypotheses regarding age differences in the proportional looking.

To test the infants' memory of the cartoons, as in Experiment 1 we calculated the proportional looking to the novel cartoon by dividing the looking time to the novel cartoon by the looking time to both cartoons and compared this with chance level (.50). Planned *t* tests revealed that only the 12-month-olds remembered this version of the cartoons as evidenced by their looking behavior. See Table 1 for descriptives and results (see also Fig. 5).

To further examine potential age differences, we again ran an ANOVA with age group (6 vs. 10 vs. 12 months) as a between-participants factor and with proportional looking time as the dependent variable. No age differences were found in this analysis, $F(2,104) = 2.58$, $p = .08$, $\eta^2_p = .05$, $BF_{10} = 0.70 \pm 0.036\%$.

Finally, to fully explore the effect of the scrambled stimuli in Experiment 2, we ran an ANOVA for the complete data set (Experiments 1 and 2) with age group (6 vs. 10 vs. 12 months) and condition (storyline/Experiment 1 vs. scrambled/Experiment 2) as between-participants factors and with proportional looking time as the dependent variable. Here, we found a clear main effect of age group, $F(2,209) = 5.85$, $p < .01$, $\eta^2_p = .05$, $BF_{10} = 7.90 \pm 0.038\%$, but no clear evidence for a main effect of condition, $F(1,209) = 3.50$, $p = .063$, $\eta^2_p = .02$, $BF_{10} = 0.71 \pm 0.023\%$, and no interaction, $F(2,209) = 0.024$, $p = .98$, $\eta^2_p < .001$, $BF_{10} = 0.55 \pm 2.82\%$ (see also Fig. 6).

The results from Experiment 2 are mixed. If we look solely at the conventional memory measure for VPC studies (testing against chance level), we see that the 6- and 10-month-olds were unable to meet the criterion for memory for the familiar stimulus in the scrambled condition (in contrast to Experiment 1). This would lead us to think that our manipulation (the storyline version vs. the scrambled version) made an important difference. However, the 12-month-olds in Experiment 2 did meet the criterion for memory just as the 12-month-olds did in Experiment 1. This finding muddies the picture, and it is surprising given that Sonne et al. (2018) found that 18-month-olds did not meet the memory criterion under the same conditions. We are inclined to interpret the finding from the 12-month-olds

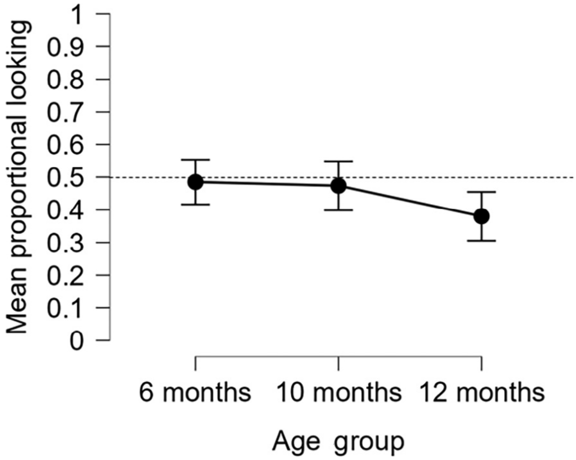

Fig. 5. Proportional looking to the novel cartoon during test for each age group. Error bars show 95% confidence intervals. The dotted line represents chance level.

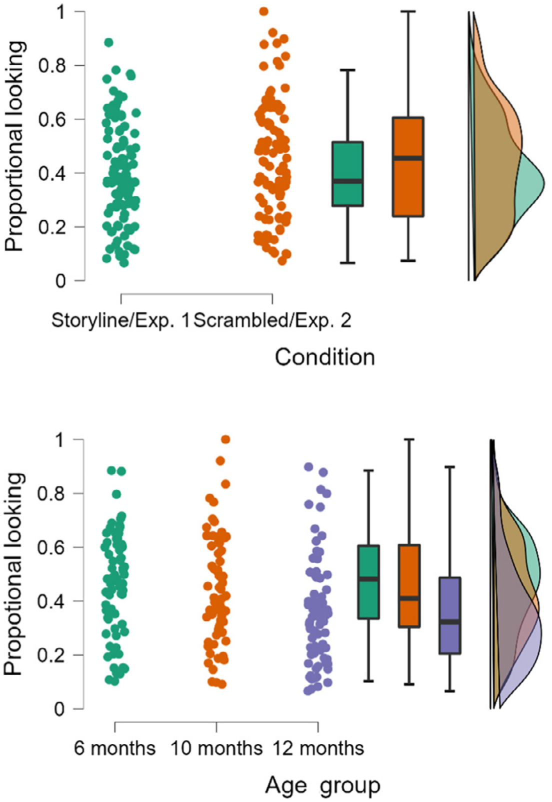

Fig. 6. Raincloud plot illustrating the distribution of the proportional looking time in the two experiments. The top panel reflects data split by experiment, and the bottom panel reflects data split by age group for both experiments combined. Exp., Experiment.

in Experiment 2 as a coincidental finding. This is based on the findings from Sonne et al (2018) but also on the fact that the ANOVA for the proportional looking data of Experiment 2 alone showed no age differences. This means that statistically (the one-sampled *t* tests apart) there are no meaningful differences among the three age-groups in a direct comparison. Therefore, we see no basis for further interpretation of age differences in Experiment 2 based on the current data. If future studies find additional evidence for a "special" case for 12-months-olds, then of course that will call for further investigation and theoretical explanation.

When we included the data from both Experiments 1 and 2 in the ANOVA, we saw that there was no convincing difference between the storyline and scrambled versions (i.e., no main effect of condition). This means that in this study we failed to convincingly illustrate the detrimental effect of stripping the cartoons of a coherent storyline. The fact that the 6- and 10-month-olds failed to meet the memory criterion in Experiment 2 may suggest that the storyline information is of some importance for remembering (in line with Sonne et al., 2018), but the overall evidence is not sufficiently strong to form the basis of any firm conclusions on the importance of storyline information, primarily due to the surprising finding from the 12-month-olds. These mixed findings warrant a discussion of the status of comparisons with a fixed (chance) level in VPC studies, on the one hand, and direct comparisons of the performance of different groups, on the other (see the General Discussion section). Nevertheless, looking at the full dataset (Experiments 1 and 2), we again find a convincing effect of age (for both conventional and Bayesian analyses). Thus, it is safe to conclude that the familiarity preference increased with age in the study overall.

General discussion

To our knowledge, this is the first study to investigate memory in early infancy for complex dynamic material using the VPC paradigm. Whereas memory for *simple* dynamic events has been documented in infancy (cf. Bahrick et al., 2002), memory for *complex* dynamic events has to our knowledge never been previously examined in the first year after birth by use of the VPC paradigm. In Experiment 1, we found that all age groups showed a familiarity preference indicating memory for the familiar cartoon. These results replicate previous findings using identical cartoons (e.g., Kingo & Krøjgaard, 2015; Sonne et al., 2016, 2018), but here with substantially younger infants. To our knowledge, this is the first experiment to document memory for such complex material across 2 weeks in young infants using the VPC paradigm. In addition, we found that the strength of the memory trace (evidenced by a familiarity preference) increased with age.

The present results are important because they provide important insights into the competencies of young infants. Hitherto, the findings from the VPC paradigm have been limited because of the stimuli used. Furthermore, other researchers have documented memory in 6-month-olds when assessed by use of other memory measures (deferred imitation and the mobile conjugate reinforcement paradigm), whereas the same infants did not show memory after a retention when tested by use of the VPC paradigm (Gross et al., 2002). The current study, however, shows that infant memory is also present for more complex stimuli even in the first year after birth as documented by use of the VPC paradigm. The cartoons used in the current study seem highly suitable for examining memory for complex dynamic material. First, the material contains complex aspects of events that—although prominent in the everyday lives of infants—have only rarely been studied. Second, the stimulus material has proven to be useful across a substantial age range, which is not always the case in developmental psychology (cf. the restricted age range for the mobile conjugate reinforcement paradigm; see Rovee-Collier & Cuevas, 2009). Thus, this stimulus material may be useful, for instance, in attempting to disentangle the enigma of when and how familiarity and novel preferences come into play during the ontogenesis (cf. Bahrick & Pickens, 1995; Hunter & Ames, 1988). Whereas the stimuli used obviously have advantages, at the same time they also contain a potential limitation. Although the cartoons allowed us to investigate infant memory for complex dynamic events, it would be interesting to investigate whether these findings would replicate to even more naturalistic events involving real people. Future studies could also examine whether even younger infants might succeed in remembering the events or explore longer retention intervals. Finally, further studies into the relative importance of static and dynamic conceptual information in different age groups are clearly warranted.

Experiment 2 was designed to give a qualified answer to the question: Was the storyline an important support for the documented memory in Experiment 1 or did the infants simply remember the cartoons due to static conceptual information embedded within the cartoons? Based on the results from Sonne et al. (2018), we were interested in examining whether infants of this young age were also affected by disturbances to the storyline. The current findings were mixed and only partly showed evidence for an effect of a(n) (in)coherent storyline. However, the strength of this evidence differs depending on whether the analytical approach compares proportional looking with a chance level (the conventional measure of memory in VPC studies) or directly compares VPC performance of different groups and/or conditions.

This issue is not unique to the current VPC study. In VPC studies, a one-sample *t* test against chance level gives us a convention-based functional threshold by which we can interpret performance of each group in terms of memory. Direct comparison of the groups' performance (i.e., the ANOVAs) is blind to this conventional threshold but allows us to statistically investigate group differences. As such, these two approaches provide us with quite different kinds of information. In the current study, the "threshold" approach (based on the VPC analyses) shows us that scrambling the storyline had a detrimental effect on 6- and 10-month-olds' memory function. The "difference" approach (based on the ANOVAs), on the other hand, shows no relative effect of the manipulation (Experiment 1 vs. Experiment 2) but shows clear age differences in Experiment 1 and overall. In part, the challenge of comparing results from these two approaches is enhanced by the dichotomous thinking of conventional alpha-level hypothesis testing (e.g., Field, 2018). Hopefully, an increased focus on more continuous hypothesis testing, such as Bayesian statistics, will allow for a more comprehensive and less dichotomous interpretation of results by looking more at the strength of the evidence than at accepting or rejecting hypotheses. For the current study, however, the Bayesian analyses support the interpretation provided by the conventional hypothesis testing.

The current study has documented memory for complex dynamic events within the first year after birth. These findings importantly add to the literature on infant memory for dynamic stimuli by documenting memory for more complex events approximating the everyday events normally experienced by infants. In addition, we found some evidence that the dynamic information (the storyline) plays a facilitating role in infant memory as operationalized here. However, future studies should seek more decisive evidence for the relative importance of dynamic and static information in VPC.

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